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Hydropower in Turkey for a clean and sustainable energy future

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Abstract

Over the last two decades, global electricity production has more than doubled and electricity demand is rising rapidly around the world as economic development spreads to emerging economies. Not only has electricity demand increased significantly, it is the fastest growing end-use of energy. Therefore, technical, economic and environmental benefits of hydroelectric power make it an important contributor to the future world energy mix, particularly in the developing countries. This paper deals with policies to meet increasing energy and electricity demand for sustainable energy development in Turkey. Turkey has a total gross hydropower potential of 433 GWh/year, but only 125 GWh/year of the total hydroelectric potential of Turkey can be economically used. By the commissioning of new hydropower plants, which are under construction, 36% of the economically usable potential of the country would be tapped. Turkey's total economically usable small hydropower potential is 3.75 GWh/year.

Keywords: Hydropower; Renewable energy; Sustainable development; Large dams

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1. Introduction

Energy is essential to economic and social development and improved quality of life in Turkey as in other countries. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on efficiency in energy production, transmission, distribution and consumption in the country. Electricity supply infrastructures in Turkey as in many developing countries are being rapidly expanded as policymakers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth. In the coming decades, global environmental issues could significantly affect patterns of energy use around the world as in Turkey [1].

Hydropower contributes one-fifth of the world's power generation. In fact, it provides the majority of supply in 55 countries. For several countries, hydropower is the only domestic energy resource. Its present role in electricity generation is, therefore, substantially greater than any other renewable energy technology, and the remaining potential, especially in the less developed countries such as Turkey, is vast. While it is not a panacea, in that it is restricted to sites with available water and appropriate geomorphology, hydropower's flexibility and proven technology sets it apart from other renewable energy sources [2].

With an estimated 95% of population growth in the coming decades likely to be in and around cities, the need for sustainable solutions with compact, interconnected power plants will be ever more pressing. Decentralized schemes, however, will remain important for rural electrification programs. Hydropower can be adaptive and flexible. Depending on the storage capacity involved, a major advantage of hydropower is that generation can be scheduled. Run-of-river schemes can be implemented to provide continuous 'base-load' generation. The operation of a cascade of several run-of-river power plants can be optimized to provide generation when it is needed. This is especially true if there is a reservoir scheme at the head of the cascade. Schemes that include a reservoir are able to store potential energy for production when the demand is highest. When water resources

are not available to replenish reservoirs by natural inflow, pumped-storage schemes have been developed to assist in the storage of energy from other generation sources. Therefore, hydropower can substantially improve efficiency in a mixed power system, reducing emissions from fossil-fuel power plants, and backing up intermittent sources such as wind power [3,4].

2. The role of hydropower in sustainable development

The hydropower industry is closely linked to both water management and renewable energy production, and so has a unique role to play in contributing to sustainable development in a world where billions of people lack access to safe drinking water and adequate energy supplies. On the other hand, approximately 1.6 billion people have no access to electricity and about 1.1 billion are without adequate water supply. However, resources for hydropower development are widely spread around the world. Potential exists in about 150 countries, and about 70% of the economically feasible potential remains to be developed mostly in developing countries where the needs are most urgent [3–5].

Hydropower is available in a broad range of project scales and types. Projects can be designed to suit particular needs and specific site conditions. As hydropower does not consume or pollute the water it uses to generate power, it leaves this vital resource available for other uses. At the same time, the revenues generated through electricity sales can finance other infrastructure essential for human welfare. This can include drinking water supply systems, irrigation schemes for food production, infrastructures enhancing navigation, recreational facilities and ecotourism.

Water is a vital resource that supports all forms of life on earth. Unfortunately, it is not evenly distributed by season or geographical region. Some parts of the world are prone to drought, making water a particularly scarce and precious commodity. In other parts of the world, floods that cause loss of life and property are major problems. Throughout history, dams and reservoirs have been used successfully in collecting, storing and managing water needed to sustain civilization. Hydropower often supports other essential water services such as irrigation, flood control and drinking water supplies. It facilitates the equitable sharing of a common vital resource. Table 1 shows the advantages and disadvantages of the hydropower option [4–6].

Hydropower has very few greenhouse gas emissions compared with other large-scale energy options (see Table 2). In addition, by storing water during rainy seasons and releasing it during dry ones, dams and reservoirs can help control water during floods and droughts. These essential functions protect human lives and other assets. This will be increasingly important in the context of global warming, which implies an expected rising variability in precipitation frequency and intensity. On the other hand, hydropower projects do not export impacts such as acid rain or atmospheric pollution. Environmental impacts are limited to changes in the watershed in which the dam is located. When well managed, these changes can sometimes result in enhancements, and other impacts can be avoided, mitigated. Hydropower can contribute to mitigating the widespread potential human impacts of climate change [4–6].

There is no single solution to the world's quest for more, cleaner energy and effective water management. Energy and water for sustainable development depend not only on supply choices, but also on how these choices are implemented. It requires the creation of a

Table 1
Advantages and disadvantages of the hydropower option

Advantages	Disadvantages
Economic aspects	
Provides low operating and maintenance costs	High upfront investment
Provides long life span (50–100 years and more)	Precipitation
Provides reliable service	Requires long-term planning
Includes proven technology	Requires long-term agreements
Instigates and fosters regional development	Requires multidisciplinary involvement
Provides highest energy efficiency rate	Often requires foreign contractors and funding
Generates revenues to sustain other water	
Creates employment opportunities and saves fuel	
Social aspects	
Leaves water available for other uses	May involve resettlement
Often provides flood protection	May restrict navigation
May enhance navigation conditions	Local land use patterns will be modified
Often enhances recreation	Waterborne disease vectors may need to be checked
Enhances accessibility of the territory and its resources	Requires management of competing water uses
Improves living conditions	
Sustains livelihoods (fresh water, food supply)	
Environmental aspects	
Produces no atmospheric pollutants and only very few GHG emissions	Inundation of terrestrial habitat
Enhances air quality	Modification of hydrological regimes
Produces no waste	Modification of aquatic habitats
Avoids depleting non-renewable fuel resources	Water quality needs to be managed
Often creates new freshwater ecosystems with increased productivity	Temporary introduction of methylmercury into the food chain needs to be monitored/managed
Enhances knowledge and improves management of valued species due to study results	Species activities and populations need to be monitored
Helps to slow down climate change	Barriers for fish migration, fish entrainment
Neither consumes nor pollutes the water it uses for electricity generation purposes	Sediment composition and transport may need to be monitored/managed

Source: Ref. [4].

level playing field among available energy options and global water governance involving all stakeholders in a participatory decision-making process. In adopting their own sustainability guidelines, the members of the International Hydropower Association are committed to developing and operating their projects, in collaboration with all stakeholders, in a way that is environmentally friendly, socially responsible and economically efficient so that hydropower projects can make a major contribution to achieving sustainable energy and resource development [4].

3. An overview of Turkey

Turkey is in the region where the three continents Asia, Africa and Europe are closest to each other, and straddles the point where Europe and Asia meet. The country is in the northern hemisphere at a point that is about halfway between the equator and the North

Table 2
The comparison of energy amortization time and emissions of various energy technologies

Technology	Energy pay back time (months)	SO_2 emission (kg/GWh)	NO_2 emission (kg/GWh)	CO_2 (Ton/GWh)
Coal fired	1.0–1.1	630–1370	630–1560	830–920
Gas (CCGT)	0.4	45–140	650–810	370–420
Large-hydro	5–6	18–21	34–40	7–8
Micro hydro	9–11	38–46	71–86	16–20
Small hydro	8–9	24–29	46–56	10–12
Wind turbine				
4.5 m/s	6–20	18–32	26–43	19–34
5.5 m/s	4–13	13–20	18–27	13–22
6.5 m/s	2–8	10–16	14–22	10–17
Photovoltaic				
Mono-crystalline	72–93	230–295	270–340	200–260
Multi-crystalline	58–74	260–330	250–310	190–250
Amorphous	51–66	135–175	160–200	170–220

Source: Ref. [36].

Pole, at a longitude of 36°N–42°N and a latitude of 26°E–45°E. It is roughly rectangular in shape and extends about 1600 km in the east–west direction, and 550 km from north to south. Turkey is surrounded by the Black Sea in the north, the Mediterranean Sea in the south and the Aegean Sea in the west. There is also one inland sea called Marmara Sea. The country has a total area of 78 million ha, of which 76.5 million ha is land and 1.5 million ha is water surface [7].

In view of its geographical location, the mainland of Anatolia has throughout historical times been the birthplace of many great civilizations. It has also been prominent as a center of commerce because of its connections to three continents and the seas surrounding it on three sides. As a result of the varied geographical conditions, Turkey shows great diversity in geological structure, topography, climate and vegetation. The country is subdivided into seven regions: four of them (Black Sea, Marmara, Aegean, and Mediterranean) are coastal units and the remaining three (Central Anatolia, East Anatolia, and Southeast Anatolia) are mountainous and subject to harsh climatic conditions [7].

The climate of Turkey is semi-arid, with extremes in temperature. The range of temperature difference between winter and summer varies from 16 to 29 °C in the eastern part of the country to 18 and 20 °C on the coastal area. Turkey is subject both to a continental type of climate characterized by cold rainy winters and dry summers and also to a subtropical climate distinguished by dry summers. On the other hand, Turkey has high seismic activity. Numerous earthquakes, some quite destructive, occur mostly along the North-Anatolian fault-line running from the Dardanelles Strait through the Pontus Mountains, in a line parallel to the Black Sea coast [7].

According to the latest population survey (in 2000), the population of Turkey is 67.80 million of which 44.00 million live in urban settlements and 23.79 million live in rural settlements. The annual population growth rate fell below 2% for the first time in history after 1945. The population in urban settlements increases at a rate greater than that in rural settlements. In the last decade, the population in urban settlements has shown a

considerable increase, rising from 56% in 1990 to 64.9% in 2000. On the other hand, the average life expectancy in the country is 71.24 years. The infant mortality rate is 4.73% and the literacy rate is 85% [7].

4. Water resources management in Turkey

Although Turkey has an adequate amount of water in general, it is not always in the right place at the right time to meet present and anticipated needs. As regards hydrology, Turkey is divided into 26 drainage basins. The rivers in general have irregular regimes, and natural flows cannot be taken directly as usable resources. The average annual precipitation, evaporation and surface runoff geographically vary greatly [7,8]. On the other hand, Turkey has 665,000 ha of inland waters, excluding rivers and small streams. There are 200 natural lakes, with a total area of 500,000 ha, and 775 dam lakes and ponds with a total surface area of 165,000 ha [7].

The amount of precipitation in any particular region usually varies from year to year but, over a long period, the average remains relatively constant. Turkey averages about 643 mm of precipitation annually, but the distribution is quite uneven. The range is from less than 250 mm in the inland areas of central Anatolia to more than 3000 mm in the northeastern Black Sea coastal region. Autumn marks the start of the rainy season, which continues until late spring on the western and southeastern coasts; whereas the Black Sea coast receives rain throughout the year.

This average annual precipitation corresponds to an average of 501 km^3 (501 billion m^3 (bcm)) of water per year. While 274 km^3 of this quantity returns to the atmosphere through evaporation–transpiration, 69 km^3 feeds the aquifers through infiltration from the surface. Thus the average annual surface water potential is 186 km^3, of which 158 km^3 comes from surface runoff and 28 km^3 of groundwater feeds the rivers. With a surface run-off of 7 km^3 volume coming from the neighboring countries, the total surface run-off within the country reaches 193 km^3. However, from the economic and technical points of view, the average exploitable water potential of the country is 110 km^3 per year [7,8].

In view of the considerable variation in runoff in terms of seasons, years and regions, it is absolutely necessary for the major rivers in Turkey to have water storage facilities, to allow for the use of the water when it is necessary. Consequently, priority has always been given to the construction of water-storage facilities. Significant progress has taken place in the construction of dams throughout the 48 years that have elapsed since the establishment of the State Hydraulic Works (DSI) [8].

With the projects developed primarily by DSI and other institutions engaged in water resources development, water consumption in Turkey reached 39.3 bcm by 2000, corresponding to only 36% of the economically exploitable water resources. During water consumption estimates on a sectoral basis, it is accepted that all of the economically irrigable land will be irrigated with irrigation schemes constructed by the year 2030 and water consumption for irrigation will be 71.5 bcm. Hence, while its share in the total consumption was 75% in 1999, the share of irrigation water in the total water consumption will be decreased to 65% by the year 2030, through the utilization of modern irrigation techniques [9].

It has been accepted that the total population of Turkey will reach 110 million by 2030, with an annual increase rate of 2%. Additionally, it is assumed that the per capita water

consumption of 280 l/day (in 2003) will reach 540 l/day by 2030. By taking into consideration that about 5.2 bcm water is needed in the tourism sector, the total water consumption for domestic purposes will reach 26.1 bcm by 2030. With the assumption of 4% annual growth rate in the industrial sector, it is expected that industrial water consumption will increase from 4.8 bcm in 2003 to 13.2 bcm in 2030. Thus, considering all of these issues that 100% of the total economically exploitable water resources will be under use by the year 2030 [7,8].

The water potential of countries is usually evaluated based on water potential per capita. According to international criteria, countries with a water potential greater than 10,000 m^3 per capita per year are accepted as water-rich; countries with a potential of 3000 to 10,000 m^3 are accepted as self-sufficient; countries with a potential of 1000–3000 m^3 are accepted as having a water-deficit; and, those with a water potential of less than 1000 m^3 per capita per year are regarded as water-poor countries [8,11].

In Turkey, while the gross water potential per capita was 3700 m^3 at the beginning of 1997, this fell to 3000 m^3 at the beginning of 2000 and it is estimated to decrease to 2000 m^3 in 2010 as a result of the population increase. However, when evaluated on the basis of the average annual exploitable potential, this figure will be about 1300 m^3. Thus, as understood from these figures, some regions of the country will face water scarcity in drought seasons and Turkey will become a water-deficit country in the future [7,8].

5. Energy utilization in Turkey

The socio-economic development, which has been progressing in parallel with fast industrial growth in Turkey, has caused living standards to rise. This has led to an increase in demand for electrical energy. All kinds of economic activities depend upon continuously developing technology and energy, and hence electrical energy has become an indispensable component of social life. An interconnected system now extends throughout the whole country, with the distribution network reaching even the smallest settlements. Electrical energy consumption has thus increased quickly as a proportion of total energy consumption [9–12].

The basic target of Turkey's national policy on energy is the provision of cheap electrical energy in sufficient amounts and on time, under qualified, reliable and competing conditions of the energy market. The energy policy, determined by 5-year development plans, is as follows [9]:

- Provision of qualified, reliable and cheap energy for sustainability in socio-economic development.
- Provision of safety in energy supply.
- Encouragement of private sector investments and expedition of privatization activities in the power sector.
- Addition of new and renewable sources as soon as possible to the energy supply cycle.

Studies to maintain power sector competition, increase productivity and provide transparency are going to be carried out to restructure the power sector and establish organizations through the Electricity Market Law [9–12].

5.1. Energy resources

Turkey has a wide variety of conventional and renewable energy resources including lignite, hard coal, asphaltite, bituminous shale, oil, natural gas, hydro, biomass, geothermal, wind and solar (see Tables 3 and 4). However, most of these are of inadequate quality and quantity. Each of its coal, geothermal and hydro reserves is estimated to be around 1% of world reserves, and its oil and natural gas reserves are negligible compared with the world total [9–13].

Table 3
Primary energy production

	1990	1995	2000	2002	2004
Hard coal (Kt)	2745	2248	2259	2245	1946
Lignite (Kt)	44,407	52,758	60,854	51,048	43,709
Asphaltite (Kt)	276	67	22	5	722
Oil (Kt)	3717	3516	2749	2420	2276
Natural gas (million m^3)	212	182	639	407	708
Hydro (GWh)	23,148	35,541	30,879	33,684	46,084
Geothermal—elec. (GWh)	80	86	76	105	93
Geothermal—heat (Ktoe)	364	437	648	730	811
Wind (GWh)			33	48	58
Solar (Ktoe)	28	143	262	318	375
Wood (Kt)	17,870	18,374	16,938	15,614	14,393
Dung (Kt)	8030	6765	5981	5609	5278
Total (Kt)	25,478	26,719	26,855	24,569	24,397

Source: Refs. [9,10].

Table 4
Primary energy consumption

	1990	1995	2000	2002	2004
Hard coal (Kt)	8191	8548	15,393	13,756	18,904
Lignite (Kt)	45,891	52,405	64,384	51,446	44,823
Asphaltite (Kt)	287	66	22	5	722
Oil (Kt)	22,700	27,918	31,072	29,624	31,729
Natural gas (mcm)	3418	6937	15,086	17,723	22,446
Hydro (GWh)	23,148	35,541	30,879	33,684	46,084
Geothermal—elec. (GWh)	80	86	76	105	93
Geothermal—heat (Ktoe)	364	437	648	730	811
Wind (GWh)			33	48	58
Solar (Ktoe)	28	143	262	318	375
Wood (Kt)	17,870	18,374	16,938	15,614	14,393
Dung (Kt)	8030	6765	5981	5609	5278
Electricity import (GWh)	−731	−696	3354	3153	−681
Secondary coal import (Ktoe)	453	1024	2184	2310	2209
Total (Kt)	52,987	63,679	81,251	78,403	87,819
Per capita consumption (Koe)	944	1031	1205	1126	1231

Source: Refs. [9,10].

Table 5
Electricity installed capacity, generation and consumption

	1990	1995	2002	2004
Installed capacity (MW)	16,318	20,954	31,846	36,824
Generation (GWh)	57,543	86,247	129,400	150,698
Import (GWh)	176		3588	464
Export (GWh)	907	696	435	1144
Gross supply (GWh)	56,812	85,551	132,553	150,018
Growth rate (%)		8.5	4.5	6.3
Net consumption (GWh)	46,820	67,394	102,800	121,141
Growth rate (%)		7.6	5.9	8.4
Net consumption per capita (kWh)	834	1092	1476	1698
Gross consumption per capita (kWh)	1012	1386	1903	2103

Source: Ref. [13].

Turkey's national energy resources consist mainly of hydraulic (126 TWh/year), lignite (105 TWh/year) and hard coal (16 billion kWh/year) resources, with a total annual average of 248 TWh. Approximately, 126 TWh of hydropower potential corresponds to 35,000 MW of generation capacity. Although 35–46% of electricity generation was provided by hydropower before 1993, the share of hydropower decreased to 23% in 2001 [9,10].

5.2. Development of electrical energy

In recent decades, in parallel with the annual average growth rate of 7.1%, the installed capacity increased from 16,318 MW in 1990 to 20,954 MW in 1995, 31,864 MW in 2002 and reached 36,824 MW by 2004 (Table 5). This corresponded with an increase in energy generation from 57,543 GWh in 1990 to 86,247 GWh in 1995 to 160,638 GWh in 2004. Since the growth in electricity production capability has been below the increase in demand in recent years, Turkey became an importer of electricity after 1997 [9,12,13].

Electrical energy consumption is one of the most important indicators of economic development and social welfare. Considering electricity consumption development by sector in Turkey, while the consumption by industry has increased, its share has decreased. During the same period, both consumption and the share increased for both the residential and services sectors; there was not a noticeable change in the transportation sector. Electrical energy production had reached 2103 kWh per capita by 2004 as given in Table 5 [12,13].

6. Hydropower development in Turkey

6.1. Historical review

Hydroelectric power plants go back some 90 years and they supply about 34% of the electricity produced in Turkey. The first production began with a 60 kW hydro plant in Tarsus, which was used only for providing lights during the initial years of the Republic of Turkey. The installed capacity taken over by the Republic was 29,664 kW,

and the electricity was available only in Istanbul, Izmir, Tarsus and Adapazarı. With the development of industry, usage of electrical energy other than for lighting started in 1930 and large industrial establishments began trying to produce their own electricity [15–19].

Water projects were initiated by the Ministry of Public Works under the leadership of Atatürk in 1932. The Electrical Power Resources Planning and Survey Administration (EIE) was then established in 1935 to define Turkey's energy demand, carrying out surveys and investigations to develop the hydroelectric potential of water resources and other energy resources. The important projects of that period were: Seyhan, Sarıyer, Hirfanlı, Kesikköprü, Demirköprü and Kemer dams and hydro plants. There were altogether 28 hydro plants, sharing 3.2% of the total energy production, by 1940. Etibank and the Bank of the Provinces were involved in the construction of small hydropower (SHP) plants and the electrification of villages and towns [17–20].

The share of hydroelectric power plants (total 18 MW) was only 4.4% when the total installed capacity had reached 408 MW in 1950. However, after DSI was established in 1954, the hydro capacity reached 412 MW within 10 years (34% of the total installed capacity), corresponding to 44% of total energy production. After 1963, "Five Year Development Plan" periods were started. In recent years, the share of thermal resources in the total installed capacity has increased, as a result of the rapid increase in natural gas plants, while the share of hydro plants has decreased (from 40% in 1990 to 31% in 2004), (see Table 6).

6.2. Hydropower potential

The gross hydroelectric potential and technically utilizable potential of Turkey are estimated as 433 and 216 TWh/year, respectively. The economically utilizable installed capacity and annual average energy generation have been determined approximately as 35,500 MW and 126 TWh/year, respectively (Table 7). The gross hydroelectric potential of Turkey is about 1% of the world total and about 14% of the European total. Although Turkey is not affluent in terms of hydroelectric energy potential, it is ranked in the first

Table 6
Electricity generation by energy resources (GWh)

Energy source	1990		1995		2000		2004	
	Produc.	(%)	Produc.	(%)	Produc.	(%)	Produc.	(%)
Hard-coal	621	1	2232	3	3819	3	11,998	8
Lignite	19,560	34	25,815	30	34,367	28	22,450	15
Oil	3942	7	5772	7	9311	7	7670	5
Natural gas	10,192	18	16,579	19	46,217	37	62,242	41
Total thermal	34,315	60	50,620	59	93,934	75	104,464	69
Geothermal	80		86		76		93	
Wind					33		58	
Tot. hydro	23,148	40	35,541	41	30,879	25	46,084	31
Total	57,543	100	86,247	100	124,922	100	150,698	100

Source: Ref. [13].

Table 7
Distribution of the hydropower potential in Turkey by project implementation status

	Number of project	Installed capacity (MW)	Total annual power generation capacity			
			Firm (GWh)	Mean (GWh)	Cumulative (GWh)	Mean (%)
In operation	130	12,251	32,984	44,388	44,034	35.0
Under construction	31	3338	6467	10,845	55,233	9.0
Final design completed	19	3570	7029	10,897	66,130	9.0
Under final design operation	21	1333	2492	4494	70,624	4.0
Planned	119	6091	10,861	22,324	92,948	18.0
Under planning	57	1978	4214	7602	100,550	6.0
Master plan completed	40	2691	5674	9195	109,745	7.0
Reconnaissance completed	107	3920	8523	15,184	124,929	12.0
Initial study completed	42	368	526	1180	126,109	1.0
Total potential	566	35,540	78,770	125,129		100.0

Source: Ref. [8].

quartile within European countries. In terms of developing water resources in Turkey, hydraulic energy generation takes a considerable portion [15–30].

The important river basins with an annual hydropower potential of more than 5 TWh are: Fırat (38,070 GWh), Dicle (16,702 GWh), Dogu Karadeniz (11,271 GWh), Çoruh (10,630 GWh), Seyhan (7968 GWh), Kızılırmak (6229 GWh), Yesilırmak (5308 GWh), Doğu Akdeniz (6212 GWh) and Antalya (5089 GWh) [9,11,22].

It is estimated that there is considerable SHP potential in Turkey. DSI has started a pre-investigation study on "The Place of Small HEPPs Within Estimated Hydroelectric Potential". These studies conclude that an additional technical hydroelectric energy potential of 57 TWh/year could be utilizable. Thirty eight TWh/year of hydroelectric energy potential, corresponding to two-thirds of this additional potential, has been estimated to be economically utilizable, so the total economically utilizable hydroelectric potential of Turkey will reach 164 TWh/year [9,21–25].

Approximately 50% of the additional potential of 38 TWh (that is, 19 TWh) could be realized as small HEPPs (hydroelectric powerplants), with installed capacities of less than 10 MW. The share of SHP potential in the total, which is 3% at present, would be 14%. On the other hand, in accordance with the results obtained from the pre-evaluation study, about 15% of the increase in 126 TWh/year exploitable energy potential might be achieved by developing additional SHP potential. However, this study gives only rough results about the additional SHP potential of the country and the potential must be evaluated more precisely, with comprehensive master plan studies for each hydrological basin [9,22,22].

6.3. Current situation

By 2004, the installed capacity and annual average energy production capability of thermal and hydropower plants in operation had reached 35,500 MW and 125,129 TWh, respectively. So far in Turkey, 566 hydro plants are at various stages of development. As of

2004, 130 plants have been put into operation, 31 are under construction and a further 405 are at various planning stages, see Table 7. The 130 hydropower plants in operation have an installed capacity of 12,251 MW and an annual average generation of 44,388 GWh. Thus, only 35% of the technically and economically utilizable hydroelectric potential has been developed.

On the other hand, 85% of the total hydro capacity in operation has been developed by DSI, corresponding to 9931 MW (49 hydro plants) and 35,795 GWh/year, respectively. The largest and most comprehensive regional development project ever implemented by DSI in Turkey is "The Southeast Anatolian (GAP) Project", which is located in the region of Southeast Anatolia on the Euprates and Tigris Rivers and their tributaries, which originate in Turkey [30].

By 2004, 203 small hydro projects (with installed capacities of less than 10 MW) were at various stages of development. When fully developed, these projects will have a total installed capacity of 849 MW and generate 3623 GWh/year. So far, 70 SHP projects have been put into operation, 6 are under construction and 127 projects are at various planning stages. In other words, 2.4% of the total economic installed capacity and 3% of the energy potential correspond to SHP projects (plants of less than 10 MW) [8,9,31,32].

6.4. Future aspects

The Ministry of Energy and Natural Resources (MENR) carries out the general energy planning studies, using an 'MAED' demand model, and TEIAS (Turkish Electricity Transmission Company) carries out energy generation expansion planning studies, using the DECADES model. The MAED model [9], which was developed by the International Atomic Energy Agency (IAEA), makes projections of the medium and long-term general electricity demand. It takes into consideration a detailed analysis of social, economic and technical systems. The model is based on low, medium and high case scenarios. It is very important to project the energy demand accurately, because decisions involving huge investments of capital are based on these forecasts.

The TEIAS has prepared the Long-Term Energy Generation Plan, taking into consideration the MAED model demand outcome. According to the Plan, the installed capacity will increase to 57,551 MW in 2010 and to 117,240 MW in 2020. The installed hydropower capacity is anticipated to increase to 18,943 MW in 2010 and to 34,092 MW in 2020. Thus, an additional 1000 MW of hydro capacity should be added to the system annually over the next 20 years. Turkey is thus seeking support for the development of all its economic potential by 2023, which is the 100th anniversary of the foundation of the Turkish Republic [11,13,22].

6.5. Developments in Turkish energy sector policies

Before the Electricity Market Law issued in March 2001, the MENR was the main body in the energy sector which reported directly to the Prime Minister. It is responsible for the preparation and implementation of energy policies, plans and programs, in coordination with its dependent and related organizations and other public and private entities. The State Planning Organization (SPO) evaluates Turkish energy needs, including production and imports. It makes investment decisions after consultation with the relevant State

Economic Enterprises (SEEs) and the Under Secretariat of the Treasury. It prepares the annual investment and finance programs of the SEEs together with the SPO [9–13].

The General Directorate of Energy Affairs, which reports to the MENR, is the body responsible for operation of the power sector as a whole. It evaluates private sector applications on the basis of BOT and BO models under Law No. 3096 and also finalizes and contracts both hydro and thermal plants. In addition, it carries out the energy pricing system, pollution problems and conservation of energy activities. On the other hand, the DSI which also reports to the MENR, is in charge of preparing feasibility and final design studies and constructing water projects, such as hydropower, irrigation, flood control, potable and industrial water supply and drainage facilities [8,9,13,24].

The Government has focused its efforts on improving and restructuring the power sector, generation, transmission and wholesale sale-purchase functions. The Turkish Electricity Generation and Transmission Corporation (TEAS) was separated into three entities in 2001. The Electricity Generation Company (EÜAS) is responsible for operation of existing power plants owned by the public. TEIAS, carries out transmission and load dispatch activities and the Turkish Electricity Trading and Contracting Company (TETTAS) carries out electricity wholesale sales and purchases. The recent Electricity Market Law has the following objectives [8–14]:

- To create a more transparent structure for the electricity sector.
- To establish an independent regulatory body to provide for the transparent and non-discriminatory functioning of the electricity market.
- To establish a financially strong and competitive electricity market and to provide reliable, high-quality and low-cost electricity to the consumers.

Following enactment of the Electricity Market Law No. 4628, the EMRA was established. It will liberalize electricity market activities to provide fair and transparent market regulation, in terms of generation, transmission and distribution, wholesale, retail companies, export/import, unbundling and tariffs. The Electricity Market Law is an important step in harmonizing Turkish legislation with the EU requirements. In addition, the Natural Gas Market Law No. 4646 was enacted in 2001 for the liberalization of the natural gas market [9,12,13].

Under this new Law, generation will be realized by the Electricity Generation Company, private sector generation companies, auto-producers and auto-producer groups. The right to generate and sell electricity will be obtained through generation licenses. Transmission will be carried out exclusively by the Turkish Electricity Transmission Company, while there are certain rules of eligibility for distribution companies. However, no treasury guarantees will be issued as was the case with Law No. 3096. Companies having retail licenses will have permission to operate in all areas, and there will not be any monopoly factor [12,13].

As a consequence of the Electricity Market Law, the autonomous EMRA Board was made responsible for the achievement of a competitive electricity market by establishing the legal framework for restructuring, enforcing the provisions of the Law, and issuing regulations. The main objective is bring about an eligible energy market based on bilateral contracts between market participants, with an eligible consumer concept that will ensure freedom for consumers to choose their suppliers [9–13].

The Electricity Market Licensing Regulation comprises the principles to regulate entrance to the market and operation in the market for each activity. The EMRA grants licenses to market participants to be engaged in market activities such as generation, transmission and distribution, wholesale, retail companies, export–import and tariffs.

The Licensing Regulation defines generation facilities based on renewable resources such as wind, solar, geothermal, wave, tide, biomass, biogas and hydrogen energy, as well as river and canal-type hydroelectric generation facilities with reservoirs and an installed capacity of 20 MW or below. In Section 3—Article 12 of the Licensing Regulation, it is pointed out that the legal entities applying for licenses for the construction of facilities based on domestic natural resources and renewable energy resources shall pay only 1% of the total licensing fee. Generation facilities based on renewable energy resources shall not pay annual license fees for the first 8 years after completion of the facilities [9–13].

Electricity Market Tariffs Regulation regulates the basic principles with regard to the pricing of transmission, distribution and retail services. This regulation deals with the basic principles of tariff practices and pricing methodology, taking transparency into consideration. The development of competition in the market and attracting new investors are very important.

The DSI investigates the optimum utilization of water resources throughout river basins in terms of the usages of water, taking into consideration social priorities. This is why the Water Utilization Agreement is necessary between DSI and any entity that desires to build and operate a hydroelectric power plant. To apply for a hydroelectric energy generation license, the legal entities are supposed to apply to the EMRA by submitting documents indicating an original or notarized copy of the water utilization agreement with DSI. The DSI prepared the drafts of the Water Utilization Agreement and Related Principles. As the Announcement pointed out, "The related legal entity is entitled to sign the Water Utilization Agreement" and the temporary document will be given if DSI approves the feasibility study of the proposed hydroelectric project prepared by any entity [8–13].

6.6. The importance of hydropower

Energy is one of the most important commodities for meeting physical needs and for enabling economic development in a modern society. Energy needs are continuously increasing and the demand for electrical power continues to grow rapidly. The world energy market has to date depended almost entirely on nonrenewable, but low cost, fossil fuels. Hydroelectric developments throughout the world provide approximately one-fifth of the world's total electrical energy. According to a study prepared for the Water and Sustainable Development International Conference in March 1998, even at a conservative estimate, the total exploitable hydro potential in the world amounts to at least six times as much [2,18,22,23,32].

Conventional electricity supply options include thermal (coal, oil, and gas), nuclear and hydropower. These technologies currently dominate global electricity generation (thermal 60%, hydraulic 20%, nuclear 17% and all others 3%, approximately). Use of cogeneration, particularly geothermal and wind generation, both for isolated supply and small- to medium-scale grid-feeding applications, is small but increasing globally [11,31,32].

The obvious benefit of a hydropower project is electrical power, which can support economic development and improve the quality of life. Hydro projects are labor-intensive during construction, as well as providing long-term employment opportunities. Roads and other infrastructure may provide local inhabitants with better access to markets for their crops, educational facilities for their children, health care, and other social services [11,32].

If the reservoir is a truly multipurpose facility, then other benefits may include flood control and provision of a more reliable and higher-quality water supply for irrigation, domestic and industrial use. Intensification of agriculture locally through irrigation can in turn reduce pressure on unlearned forest lands, intact wildlife habitat, and areas unsuitable for agriculture elsewhere. In addition, reservoirs can provide for fisheries and the possibilities for agricultural production in the reservoir drawdown area, which in some cases can more than compensate for losses in these sectors arising from dam construction [2,3,10,11,22,23].

The generation of hydropower provides an alternative to burning fossil fuels or nuclear power, which allows for the power demand to be met without producing heated water, air emissions, ash, or radioactive waste. Of the two alternatives to hydropower, in the last decade, much attention has been given to thermal power production because of the adverse effect of CO_2 emissions. With the increasing threat of greenhouse gases originating from such anthropogenic activities on the climate, it was decided to take action. Thus the Framework Convention on Climate Change was enacted on 21 March 1994 and has been signed by 174 countries to date.

By 2002, the total world annual consumption of electrical energy was around 15,200 TWh (102 TWh in Turkey). About 3400 TWh of this amount (22%) was produced by hydroelectric power plants [3]. If this amount of energy was to be produced in thermal power plants, then 1.7–2.4 billion t/year CO_2 would be emitted into the atmosphere. Considering both the importance of energy for development and conservation of the environment, from the viewpoint of obeying the Framework Convention on Climate Change rules, hydroelectric power plants are the best available and most environmentally friendly form of energy generation [33–36].

Hydropower is solar energy in a naturally and ideally concentrated form that can be utilized with the help of a mature and familiar technology with unsurpassed rates of efficiency. Moreover, it does not deprive future generations in terms of raw materials, or burdening them with pollutants or waste. Hydroelectric power plants utilize the basic national and renewable resource of the country. Although the initial investment cost of hydropower seems relatively high, the projects have the lowest production costs and do not depend on foreign capital and support, when considering long-term economic evaluation [35].

Dams that produce electricity by this most productive renewable clean energy source in the world provide an important contribution to the reduction of air pollution. The result of an investigation held in the USA suggests that the productivity of HEPPs is higher than 90% of thermal plants and this figure is twice that of thermal plants. In case of Turkey, the public has been wrongly informed. Some people have claimed that hydro plants do not produce as much energy as planned because of irregular hydrological conditions and rapid sedimentation of reservoirs. It is also claimed that the cost of the removal of dams entirely filled by sediment at the end of their physical lives is not considered in the total project cost, and that there are major problems in recovering the cost of investment and environmental issues [36].

7. Future energy and emissions projections

Turkey's demand for energy and electricity is increasing rapidly. Since 1990, energy consumption has increased at an annual average rate of 4.3%. As would be expected, the rapid expansion of energy production and consumption has brought with it a wide range of environmental issues at the local, regional and global levels [33–34]. With respect to global environmental issues, Turkey's carbon dioxide (CO_2) emissions have grown along with its energy consumption. Emissions in 2000 reached 211 million metric tons. Table 8 shows direct and indirect greenhouse gas emissions in Turkey by sectors between 1980 and 2010 [34–37].

Based on the demand forecast from MAED, total final energy consumption grows at an average rate of 5.9% per year from 65.5 mtoe (2000) to 273.5 mtoe (2025). Average annual growth rates vary by sector, with industry having the highest rate at 7.6%, followed by the transportation sector with 5.0% [34]. Between, 2000 and 2025, industrial consumption increases from 23.9 to 148.9 mtoe increasing its share from 36% to 54%. On the other hand, in terms of final energy by fuel, hard coal/coke increase their share slightly from 13% to 18%, lignite holds steady at 6%, electricity grows from 17% to 24%, oil products decline from 42% to 29% and natural gas increases from 7% to 17% between 2000 and 2025. The model also projects fuel mixes for each of the consumer groups or demand sectors [34].

Total natural gas consumption is projected to increase at an annual rate of 9.6% from 15.0 to 169.4 bcm over 2000–25. Power sector gas demand is one of the main drivers for this projected growth and will account for 112.8 bcm or 67% of total gas consumption in 2025. Industrial demand is the fastest growing market segment with gas expanding from 2.5 to 38.4 bcm during 2000–25 and eventually accounting for 23% of total gas consumption. New capacity additions are projected to total about 108 GW by 2025. WASP results indicate that the majority of the load growth is met with natural gas-fired generation. By 2025, gas-fired units represent 67% (93 GW) of the installed generating capacity and account for 77% of total generation [34].

Primary energy supply is projected to increase from 64.5 mtoe (1995) to 332.0 mtoe (2025). Crude oil imports remain constant at 33.0 mtoe after 2004 when the domestic

Table 8
Direct and indirect greenhouse gas emissions in Turkey between 1970 and 2010 (Gg)

GHGs	1980	1985	1990	1995	2000	2005	2010
Direct GHGs	110,216	133,056	200,720	241,717	333,320	427,739	567,000
CO_2	81,889	108,923	177,973	211,229	303,079	397,351	535,966
CH_4	27,574	23,265	21,618	24,302	25,585	25,531	25,640
N_2O	753	868	1128	6116	4656	4858	5394
NO_x	380	493	680	814	1154	1513	2073
CO	2936	3115	3715	3961	8390	9552	11,433
MNVOC	360	380	524	599	1415	1638	1991
SO_2	131	420	813	894	1038	1038	1038

GHGs: Greenhouse gases.
Source: Ref. [7].

refineries are forecast to run into their processing capacity, resulting in a drop in crude oil share from 44% to 10% of total supplies. Once the refining capacity is reached, net imports of refined products quickly grow from 2.6 to 52.3 mtoe (2000–25), accounting for about 16% of total supplies by 2025. Natural gas quickly increases its share from 10% (6.3 mtoe) in 1995 to 42% (139.8 mtoe) of total supplies in 2025. Although renewables double over 2000–25, their share decreases from 14% in 2000 to 7% in 2025 [9,14,33,34,37].

The model projects total CO_2 emissions to increase at an average rate of 5.8%/year and reach 871 million t/year by 2025. The industrial contribution changes the most noticeably, rising from 31% to 42% driven by the high growth in industrial final energy as well as the continued reliance on solid and liquid fuels in this sector [34].

Total national SO_2 emissions reach their low point as 1.83 million t/year in 2001, but it will be more than double value to 3.85 million t/year in 2025. The majority of the emissions growth can be attributed to an increase in industrial solid fuel and fuel oil combustion and an associated rise in SO_2 emissions from 566 to 2411 kt/year over 2000–25. By the end of the study period, industry is expected to be responsible for 63% of Turkey's SO_2 emissions [33]. While in 2004, electricity generation accounted for 60% of national sulfur emissions; this share will be down to 24% by 2025.

Results show that under the Renewables Scenario, 7250 MW of gas-fired capacity is substituted for 19,250 MW of wind and 1107 MW of small hydro over 2000–25. By 2025, all renewables combined (including large hydro) amount to more than 54 GW or 35% of installed capacity. The additional generation from renewables quickly increases to 53.8 TWh (7% of total) by 2025 and essentially replaces CCGT generation with only minor changes in the dispatch of the other fossil fuel units. Combined with large hydro and geothermal, renewables generate 173.6 TWh (22.6%) of electricity by 2025 [34].

8. Conclusions

Hydropower has an extensive list of positive characteristics. In addition to power generation and efficiency, it has advantages such as: flood protection, flow regulation, multiple use, fossil fuel avoidance, a long depreciation period, revenue by an adequate electricity rate, and low operating–maintenance–replacement costs. In addition, hydro plants are often superior to other power plants from the standpoint of socio-economic and environmental considerations. The environmental impacts of hydropower plants are at the lowest level compared with the other alternative resources [1–6].

Important points being considered as Turkey seeks to avoid an electrical energy 'bottleneck' in the coming years are: support of policies which will encourage private sector participation; improving hydraulic energy for sustainable socio-economic development; and, the creation of additional financial resources for the public budget. Additional important targets are: to decrease the financial burden on the State budget, which has limited resources; to provide technology transfer; and, to accelerate the economic development of the country by implementing hydraulic energy investments on schedule [11,15–20,32,35].

In view of the low operational costs of hydropower, related to not having any fuel expense, hydro plants can easily fit load demand, while having a long economic life and low environmental impacts compared with alternative energy resources. Additionally, hydro plants with large reservoirs have multipurpose benefits and profitability, such as flood protection, storing water for domestic water supply, industry and farms, fisheries,

navigation, access roads and the potential for a previously inaccessible and remote area to develop economically [36,37].

The environmental impacts of hydro plants are minimal compared with alternative resources. They make use of our renewable ‘‘green energy’’ resource, without causing pollution and CO_2 emission. They have considerable advantages; since they use the renewable sources of the country, are free of fuel costs and their design and construction can be performed by Turkish engineers and contractors. They are also easily adaptable to the system load demands [11].

As regards small hydro plants, according to the hydrological and topographical conditions of the country, it is estimated that there is considerable amount of SHP potential in Turkey. Since the investment costs of small plants are high when they are implemented individually, it would be useful to standardize the manufacturing of electromechanical equipment and build them in groups, to decrease transmission and distribution costs. In view of the privatization policy, strategies oriented towards technical aspects, as well as legislative and administrative issues, must be clarified so as to mobilize and accelerate small hydro development in Turkey [11,21].

Maintaining competition in the power sector, to increase productivity and provide transparency, are other important aims of the policy. Restructuring studies for the power sector and the establishment of organizations to determine the necessary rules and regulations for the sector according to the Electricity Market Law, are being carried out to ensure this. On the other hand, it is important to point out the restructuring policies that are directing the development of new and renewable energy, and giving special emphasis to socio-economical bodies, laws and legal regulations. In this respect, particular attention and priority should be given to the development of the hydroelectric potential in Turkey, since it is the most important natural renewable resource and only 35% of the technically and economically utilizable hydro potential has been developed so far [9–14].

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